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The American Building and Unitary Heat Pump Market: Today and Tomorrow

A. Introduction

It is a well established fact that most (35 - 45 %) of our primary energy in developed countries is used in buildings. In particular, the major portion of this energy is used in the private sector for space heating, space cooling, climate control and hot water production. As a country, the U.S. defines not only the largest (per capita) set of energy consumers in the world but also the largest market and market potential for energy saving devices and energy conservation measures. In as far as numbers go there are about $2 \cdot 10^6$ new housing starts per year in the U.S. *

In the light of these points a detailed U.S. study was undertaken on the energy effect of changes in building codes and their influence on a unitary heat pump market. Below the sample building stock codes in the private sector are identified and calculations are performed for a typical 'average' building design representative of that stock.

B. The 'Average' Building and its relevant Codes

During his Sabbatical at the P.F.A. Prof. W. Duff of the Colorado State University did a study to define a typical 'average' building design which could be used as a design standard for this study. The standard house which was the outcome of this study was a split level with a half basement. Its essential dimensions are:

1. total floor area: 162 m^2
2. total house volume: 400 m^3
3. total external wall (+ window) plus roof area: 220 m^2
4. total window plus door area: 28 m^2

This house design is 'built', in each of the eighteen locations considered, with various construction codes. These codes reflect:

1. The retrofit market (1945 - 70): Retrofit code,
2. Present building practice (1973 -): H.U.D. minimum standards,
3. Near future trend ($\sim$ 1981): New U.S. legislation,
4. A possible far term goal: Philips Experimental House Standards,

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* The total U.S. housing stock at present is about $75 \cdot 10^6$ housing units.

and, their details * (e.g. thickness of insulation used) are location dependent. Moreover, the construction materials used (e.g. El Paso-masonry, Madison-wood frame) are also location dependent.

C. The Energy Requirements of Buildings

In a less general independent study done by Rosenfeld et al. (1) (see Fig. 1), where a 100 m^2 ranch house in 5 cities was used as a standard, curves were produced for the (Fuel input equivalent) ** as a function of (Celcius degree days) for various construction codes. Also included in this study are the actual costs of changing from current practice codes, for new construction, to other codes.

It is observed by comparing the energy requirement results of Fig. 1 for Madison Wis. (4000°C days), New York N.Y. (3000°C days) and Alburquerque N.M. (2500°C days) with our results for our four codes as given in Figs. 2a-d that our:

1. Retrofit code is equivalent to their U.S. stock
2. H.U.D. Minimum Standards lies between their HUD MPS 74 and HUD current practice
3. New U.S. Legislation lies between their LBL optimum: med. infilt and LBL. optimum: lo. infilt.
4. Philips Experimental House Standards is equivalent to their LBL optimum: Passive + insulating shades.

This comparison indicates that two independent studies have adopted a similar choice of future codes as a basis for comparison. Moreover, using two different standard building designs it is seen that the heating requirement per 100 m^2 of floor area of the existing standards are almost the same in each study.

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* with the exception of code 4, they are degree-day dependent.

** Fuel input equivalent = 1.5 x Heating requirement

(1) A.H. Rosenfeld et al., "Building Energy Use Compilation and Analysis (BECA) an International Comparison and Critical Review", Lawrence Berkeley publication LBL-8912 (July 1979).

TABLE 1

APPROXIMATE

HEATING REQUIREMENT

(10^3 KWH/100 $m^2 \cdot y$)

CODE	AREA				
	max. N-Central	min. S-Central	Chicago	New York	Los Angeles
Retrofit	30	6	24	19	12
H.U.D. min.	22	3	18	13	8
New U.S.	9	0.5	7	5	1
Philips Exp'l. House	2	0	1	0.5	0

As indicated above the location data base for the present study were eighteen cities in the U.S. In order to obtain the Iso-heating requirement curves (Figs 2 a-d) the Iso-points were calculated by linear extrapolation in those areas where changes in micro climate between points were small and by a weighted fit (e.g. using °C day results) were geographical influences (e.g. the Rockies) would limit the simple linear approach. This resulted in an inter curve accuracy of better than ± 5 - 10% at points lying on the curves and in between the eighteen cities.

From Fig. 2 it is observed that the maximum heating requirement for the Retrofit code in the U.S. excluding Alaska is about $30 \cdot 10^3$kWh/100 $m^2 \cdot y$ and the minimum about $6 \cdot 10^3$ kWh/100 $m^2 \cdot y$. The high population areas about Chicago, New York and Los Angeles require $24 \cdot 10^3$, $19 \cdot 10^3$ and $12 \cdot 10^3$ kWh/100 $m^2 \cdot y$ repsectively. To put these numbers into perspective one should look at Table 1 where the other codes are also considered. On an average it can be said that if todays housing stock in the U.S. would be completely changed over to the H.U.D. min. standard then roughly 30% ($1 \cdot 10^{12}$ kWh)* of the total energy required for heating today can be saved. Moreover, if todays housing stock could be changed over to the New U.S. legislation or the Philips Experimental House standards then 75% ($2.3 \cdot 10^{12}$ kWh) or 95% ($2.9 \cdot 10^{12}$ kWh) savings could occur.

D. Required Heating and Cooling Capacity

The usual approach to calculating the required heating and cooling** capacity (kW) of a building is to use the ASHRAE design temperature method (2). These Iso-design temperature values are given for the case of heating in Fig. 3.

Using our dynamic calculation method it was possible to find, for each city and house code, the required heating and cooling capacity. This was done by identifying the peak demand for the worst day of the year as found by

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* It should be noted that the total energy consumption of the U.S. is about $23 \cdot 10^{12}$ kWh.

** including latent heat effects

(2) ASHRAE Handbook of Fundamentals, George Banta Co. Inc. U.S.A., Chapter 33 (1974).

our dynamic program. The resulting Iso-required heating and cooling capacity curves are given in Figs. 4 a-d for the four codes.

From Fig. 4 it is seen that the maximum heating and cooling capacities required for the Retrofit code are about 12.5 kW/100 m^2 and 5.0 kW/100 m^2 respectively. Moreover the minimum values for the heating and cooling capacities are 3 kW/100 m^2 and 2 kW/100 m^2 respectively. The high population areas around Chicago, New York and Los Angeles require 10.5, 9 and 4 kW/100 m^2 heating capacity repsectively, and 3, 3, and 2 kW/100 m^2 cooling capacity respectively. These numbers can be compared to those for the other codes by looking at Tables 2 and 3. It is observed that on the average if todays housing stock in the U.S. would be completely changed over to the H.U.D. minimum standards then, roughly, a 25% decrease in the required capacity of a heating unit and a 20% decrease in the required capacity of a cooling unit would be possible. Moreover, if todays housing stock could be changed over to the New U.S. legislation or the Philips Experimental House standards then a 65% and 30% or 90% or 55% decrease in the required heating and cooling capacity respectively would be possible. These numbers point to the fact that it is easier to decrease the total heating/cooling requirement than the required capacity with code changes and that code changes tend to have * a greater effect on heating than cooling.

E. Electric Unitary Heat Pumps

A simple calculation using the design temperatures indicates that the heating and cooling COP's ** (see Table 4) for well designed air to air or air to water unitary heat pump systems, in most locations in the U.S., are within about ± 20% of each other. Assuming that these COP's are the same for a unitary heat pump one may take the Iso-required heating and cooling capacity curves and find out where the required capacities are coincident.

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* Because internal and external loads to buildings have an advantageous effect on heating but a detrimental effect on cooling.

** COP_{Heat} = (H.P. Energy to House)/(Total electrical Auxilliary)
COP_{Cool} = (H.P. Energy removed from House)/(Total electrical Auxilliary) including latent effects

TABLE 2

Approximate Required Heating Capacity
(kW/100 m^2)

CODE	AREA				
	max.	min.	Chicago	New York	Los Angeles
Retrofit	12.5	3	10.5	9	4
H.U.D. min	9	2	8	7	2.5
New U.S.	4.5	1.5	4	3	1.5
Philips Exp'l House	1.5	0	1.2	1	0

TABLE 3

Approximate Required Cooling Capacity
(kW/100 m^2)

Code	AREA				
	max.	min.	Chicago	New York	Los Angeles
Retrofit	5	2	3	3	2
H.U.D. min	5	1.5	2.5	2.5	1.5
New U.S.	4	1	2	2	1.5
Philips Exp'l House	2	0.5	1.2	1.5	0.5

Fig. 5 shows such a coincidence line for the Retrofit code. It is seen that the required capacities coincide at power ratings between 5 - 8 kW (or 3 - 5 kW/100 m^2). It is, however, more sensible to look at a coincidence band. Fig's 6 a-d give the ± 20% coincidence band for the required heating and cooling capacities in the U.S. for the four codes.

One can see from Fig. 6 for the Retrofit code that the main population areas where a unitary heat pump market would be of interest stretches from Texas in the west directly to South Carolina in the east. One other population area where the coincidence band passes is the lower part of Southern California. In fact, it is in these areas where, for the past 20 years, such a unitary heat pump market has developed.

Fig. 6 also shows the coincidence band for the H.U.D. minimum standards. Although it stretches slightly more northward (up to North Carolina and Tennessee) it presents essentially the same picture and so market as was the case for the Retrofit code. Here the coincident required capacities span a slightly lower range i.e. 5 - 7 kW (3 - 4.3 kW/100 m^2) than the Retrofit code. The new U.S. legislation, however, presents a new picture. Here the coincidence band has not only moved northward but has broadened considerably. It now covers almost the whole eastern seaboard from Georgia to Vermont and, with the exclusion of the high population areas near the Great Lakes, it moves westward to cover almost all of California. This new U.S. legislation presents an interesting new market which will start up around 1981 and require unitary heat pump systems of 3 - 5 kW thermal (2 - 3 kW/100 m^2) or about 1 - 2 kW electric (0.6 - 1.2 kW/100 m^2). This kind of a market is well within the compressor range defined by companies who today produce freezers and refrigerators if modularized multistaged units are built. In particular, 2 - 5 0.5 kW stages would satisfy most of the market needs. A further code improvement to a Philips Experimental House code (see Fig. 6d) moves the coincidence band further northward away from the eastern seaboard and the high population areas of California. The only high population areas it now crosses are about the Great Lakes area and the typical required capacity for this code is about 1.5 kW thermal (1 kW/100 m^2) or about .6 kW electric (0.4 kW/100 m^2). Here one or at most two 0.5 kW stages would be required.

TABLE 4

Design COP's for Heating or Cooling

	Chicago	New York	Los Angeles
Heating	2.4	2.6	3.4
Cooling	2.6	3.0	3.0

F. Conclusions

It has been shown that the locations in the U.S. where a unitary heat pump market may develop are quite dependent on the building codes adopted in the U.S. In particular a large unitary heat pump market (about $1 \cdot 10^6$ new housing units/year) will most likely start when the new U.S. legislation is passed in 1980 - 82. If on an average 3 - 4 staged 0.5 kW compressors are used this market will require about $3 - 4 \cdot 10^6$ compressors (unitary heat pump units) per year and about $1 \cdot 10^6$ sets of controls plus logics per year for new housing units only. This up-coming market is therefore just about the size of the present American refrigerator market.

Although this is far from a complete study as it mainly addresses electrically driven heat pumps and does not take into account various systems variants or more importantly the effect of local pricing structures for electricity * it is a clear indicator of market tendencies. Moreover, the choice of a unitary heat pump market in this study was based on the fact that this market would have the highest penetration capability **.

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* electricity costs vary by a factor of about 5 across the U.S.

** if a system is always in use it must give the fastest rate of return on investment.

Fig. 1

U.S., ENERGY FOR SINGLE FAMILY RESIDENTIAL SPACE HEATING

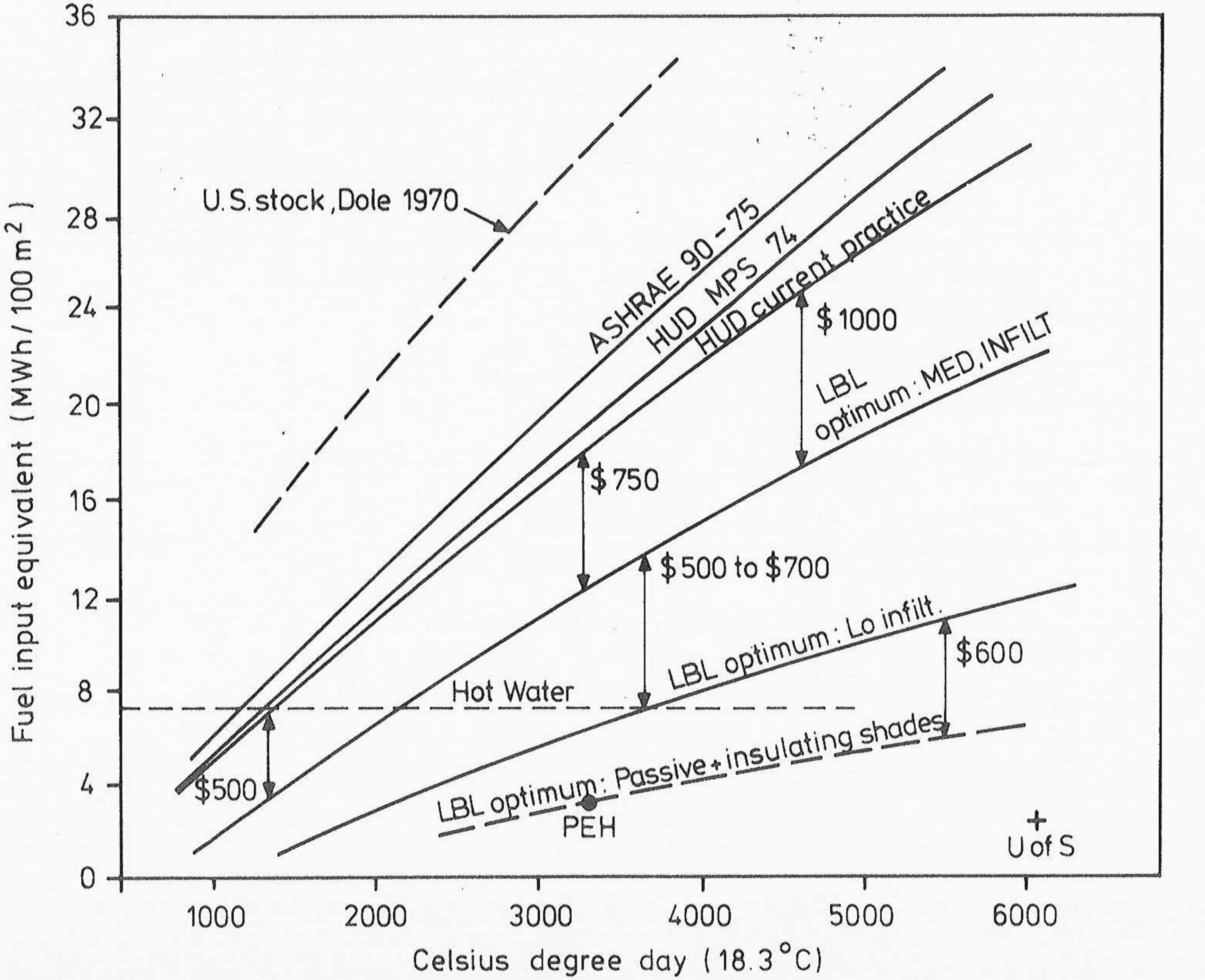
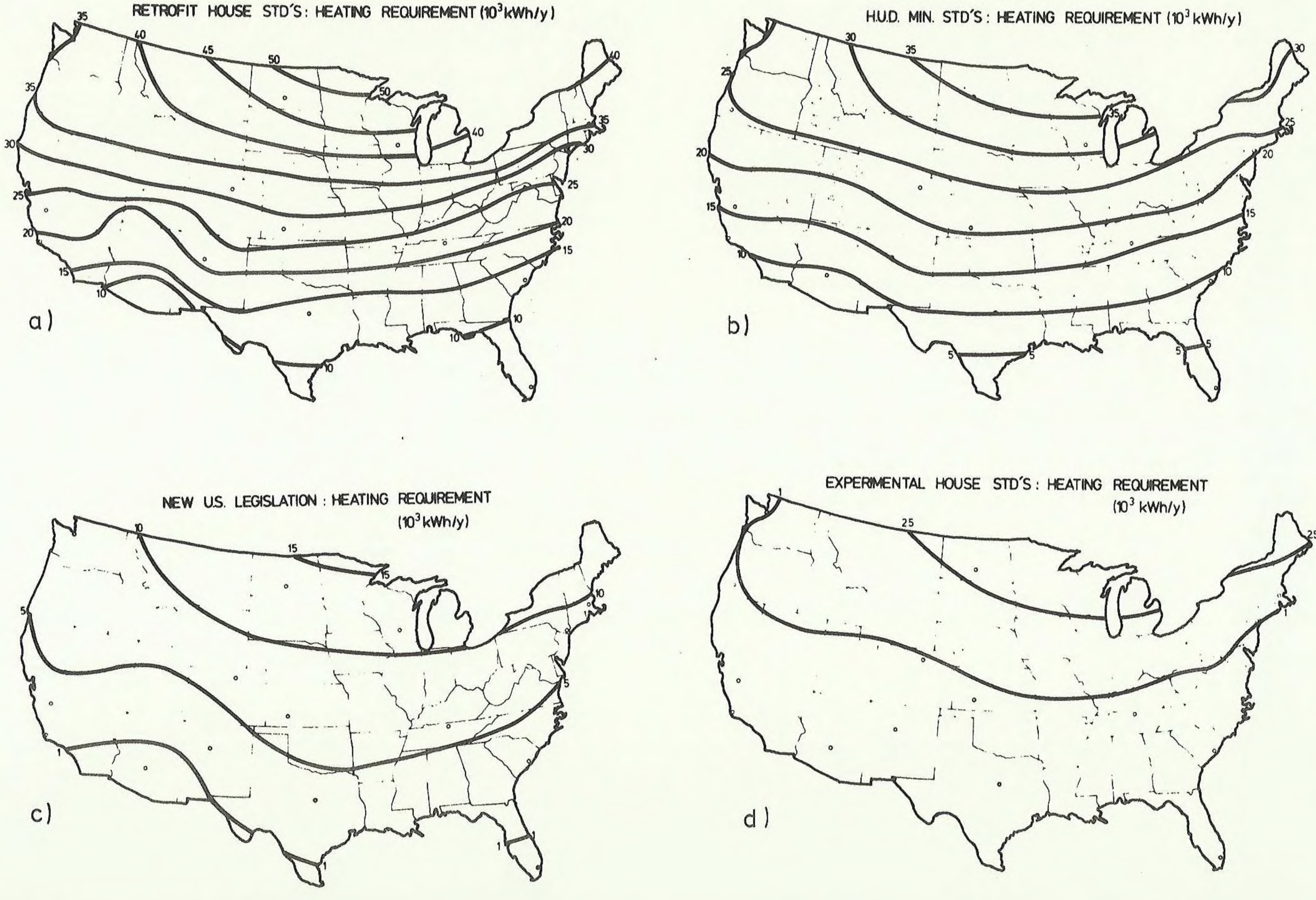


Fig. 2



RETROFIT HOUSE STD'S: HEATING REQUIREMENT (10^3 kWh/y)
a)
H.U.D. MIN. STD'S: HEATING REQUIREMENT (10^3 kWh/y)
b)
NEW US. LEGISLATION : HEATING REQUIREMENT
(10^3 kWh/y)
c)
EXPERIMENTAL HOUSE STD'S: HEATING REQUIREMENT
(10^3 kWh/y)
d)

Fig. 3 REQUIRED HEATING CAPACITY IN °C DESIGN TEMPERATURE

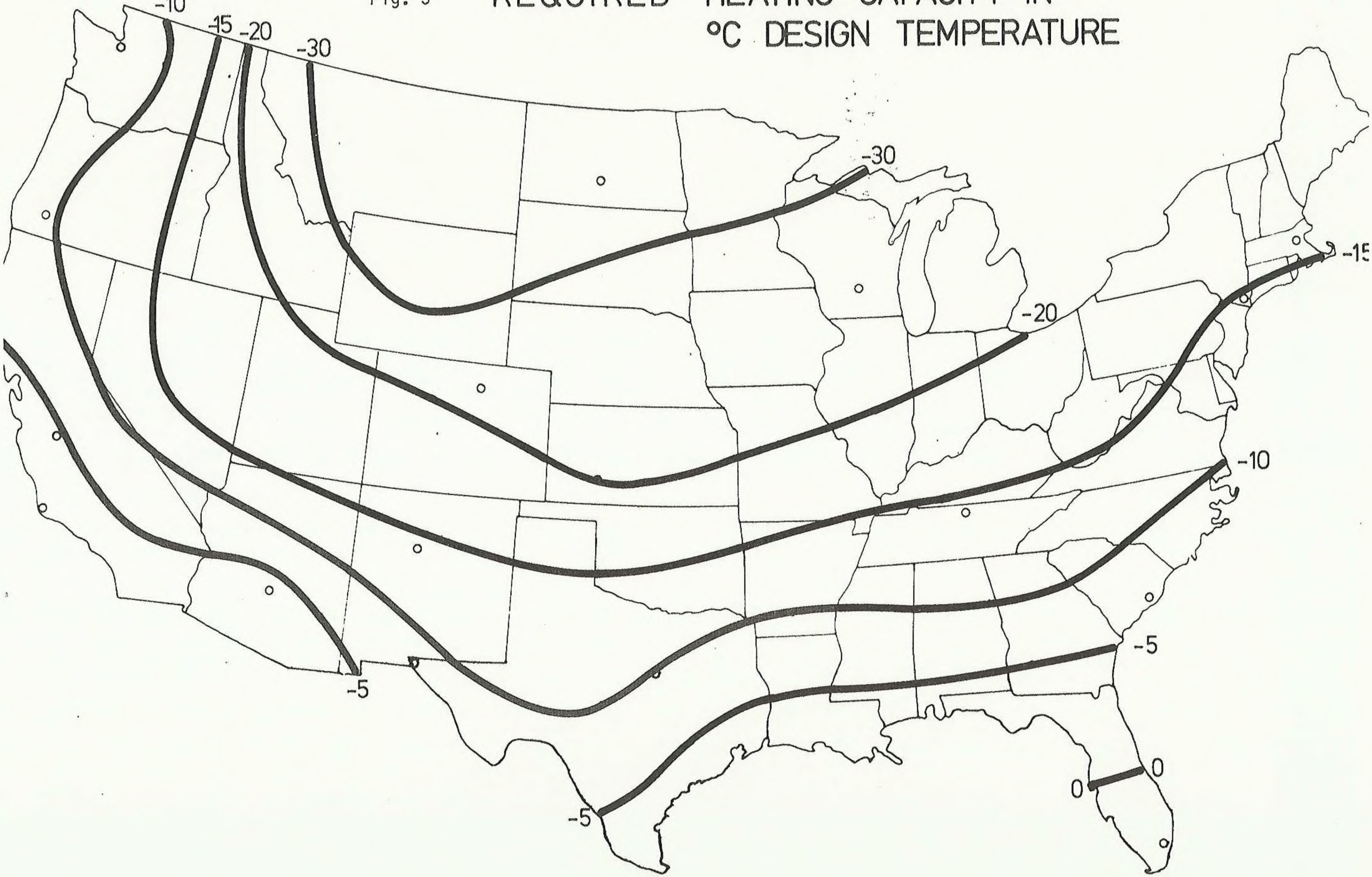


Fig. 4

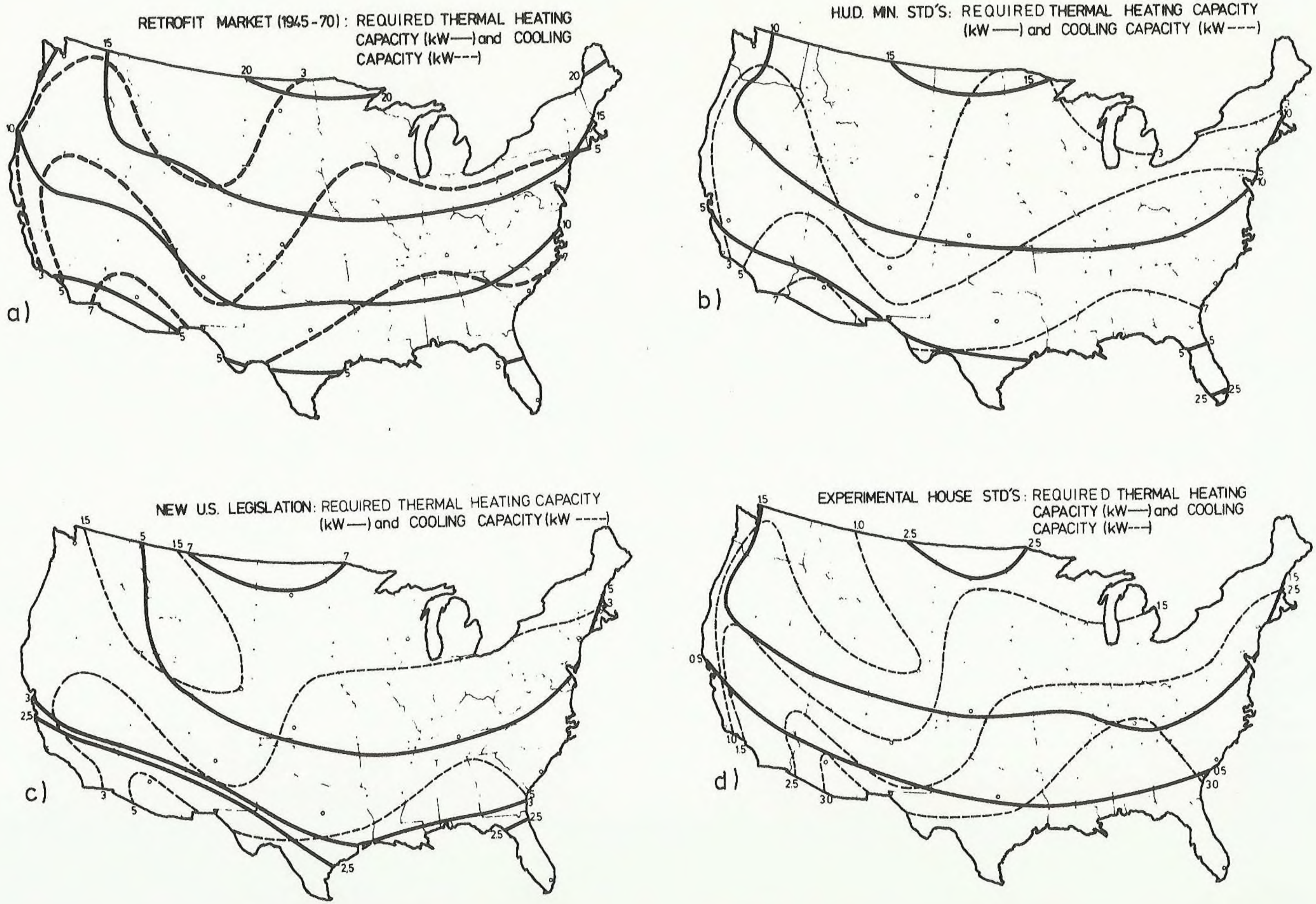

a)
RETROFIT MARKET (1945-70): REQUIRED THERMAL HEATING CAPACITY (kW——) and COOLING CAPACITY (kW---)
b)
H.U.D. MIN. STD'S: REQUIRED THERMAL HEATING CAPACITY (kW——) and COOLING CAPACITY (kW---)
c)
NEW U.S. LEGISLATION: REQUIRED THERMAL HEATING CAPACITY (kW——) and COOLING CAPACITY (kW ----)
d)
EXPERIMENTAL HOUSE STD'S: REQUIRED THERMAL HEATING CAPACITY (kW——) and COOLING CAPACITY (kW---)

Fig. 5 COINCIDENCE LINE for REQUIRED HT/CO CAPACITY (5-8 kW thermal x-pts.) (RETROFIT (1945-70) HOUSE MARKET)

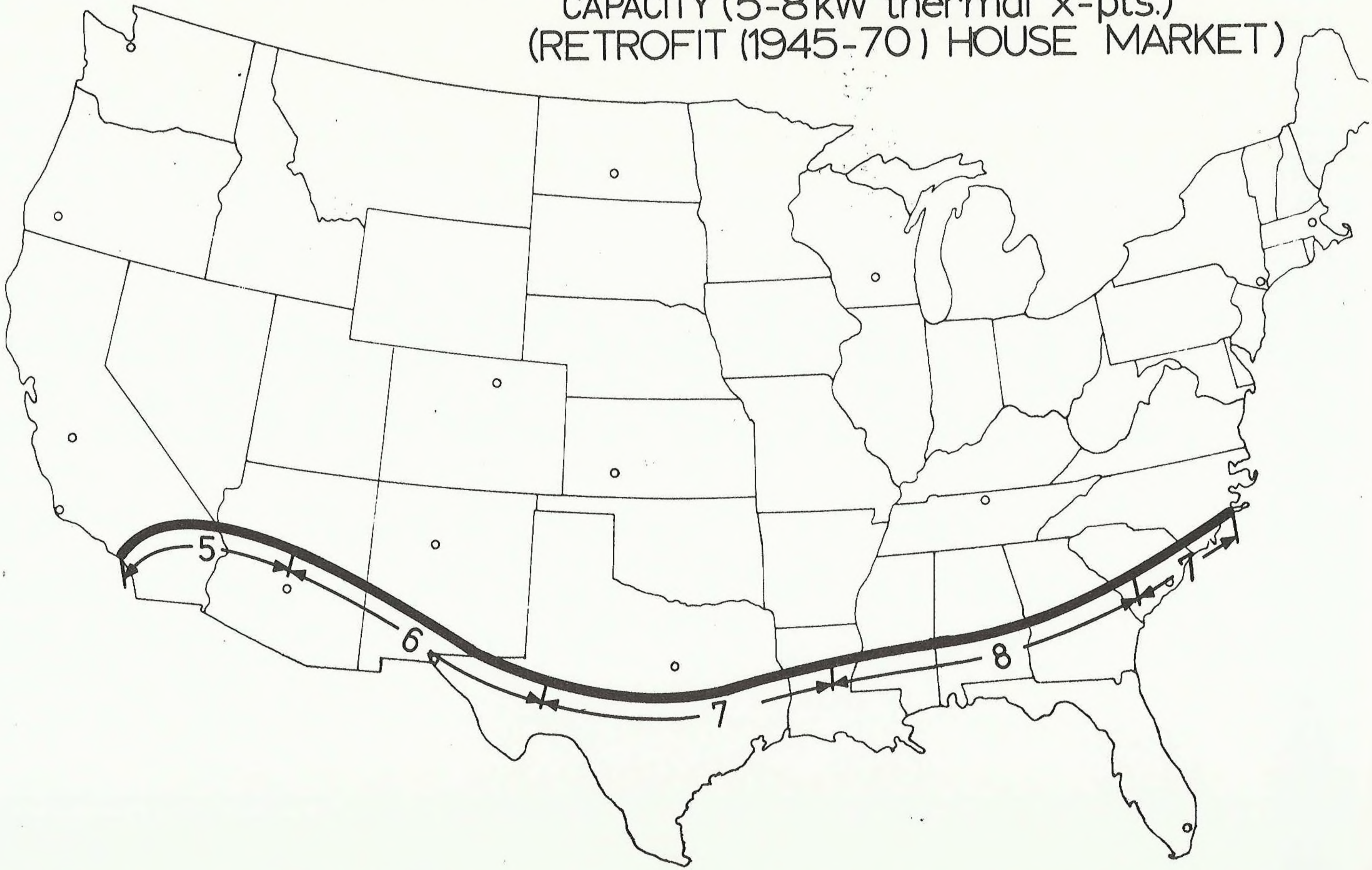
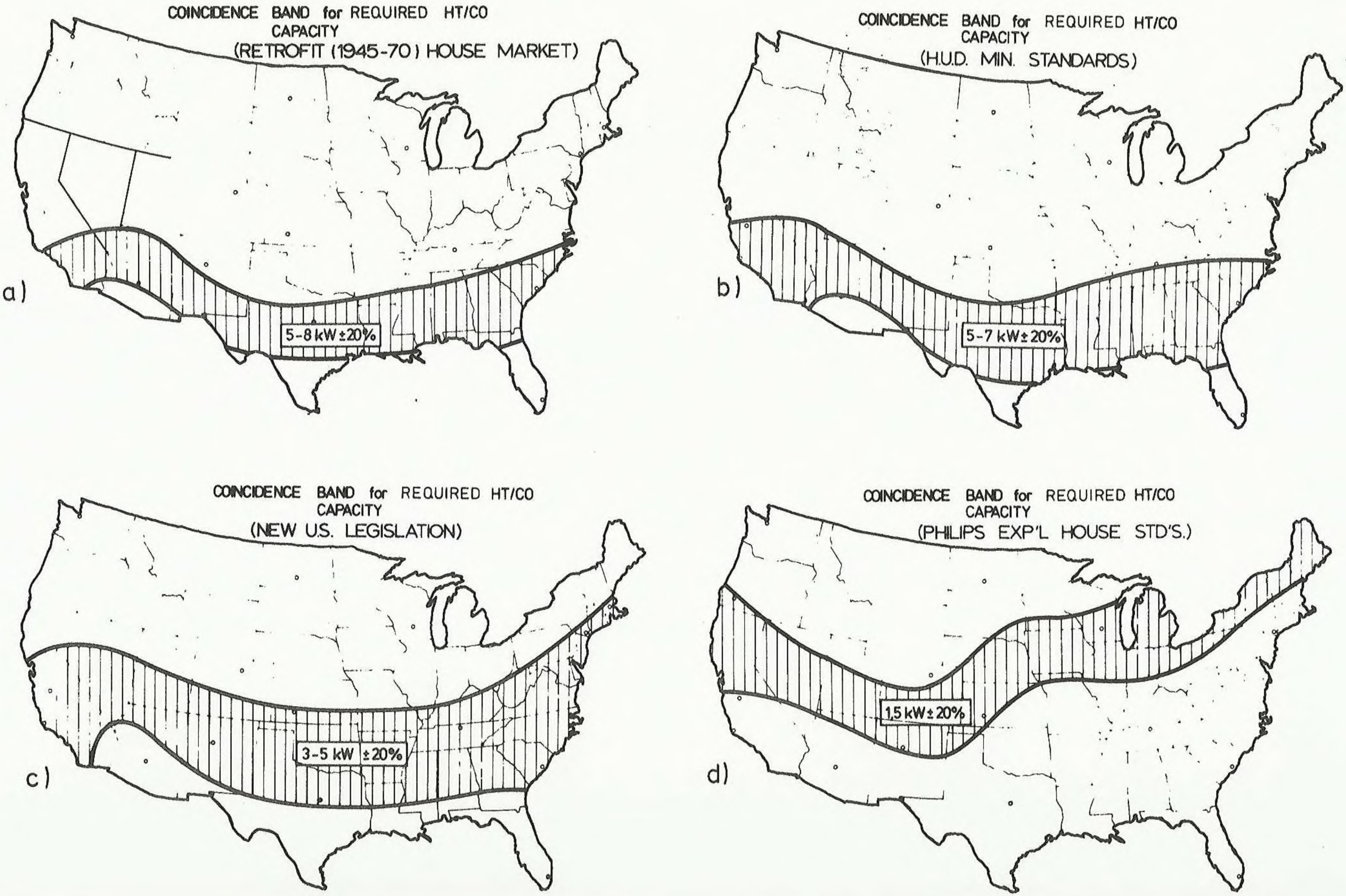


Fig. 6


COINCIDENCE BAND for REQUIRED HT/CO CAPACITY
(RETROFIT (1945-70) HOUSE MARKET)
5-8 kW ± 20%
a)
COINCIDENCE BAND for REQUIRED HT/CO CAPACITY
(H.U.D. MIN. STANDARDS)
5-7 kW ± 20%
b)
COINCIDENCE BAND for REQUIRED HT/CO CAPACITY
(NEW U.S. LEGISLATION)
3-5 kW ± 20%
c)
COINCIDENCE BAND for REQUIRED HT/CO CAPACITY
(PHILIPS EXP'L HOUSE STD'S.)
1,5 kW ± 20%
d)